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THE CF-105 ASSESSMENT STUDY

SUMMARY REPORT 11

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Compiled by

R.S. Mitchell, F.W. Slingerland & J.T. Macfarlane

DEFENCE RESEARCH BOARD

CANADIAN ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

Valcartier, Quebec

March, 1958

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SUMMARY REPORT II

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FOREWORD

This technical memorandum is a review of the portion of the CF105 Assessment Study carried out in the period from April 1, 1956 to April 1, 1958. The investigation has been carried out by CARDE for the Director of Systems Evaluations of the RCAF, under terms of reference laid down by that directorate. The Defence Research Telecommunications Establishment and the Director of Air Intelligence assisted in certain specialized portions of the study, and some contractual support was obtained.

The material herein is intended to outline the aspects of the system that have been studied and to indicate overall results, trends and recommendations. Valuations given should be regarded as smoothed results based on multi-parameter data. Where specific cases are of interest or a more detailed examination is required the reader is referred to the reports listed on pages 35 and 36.

SUMMARY

This report is a summary of the general results and trends that emerged from the CARDE, CF-105 Assessment Study. Discussion of the actual work has been kept to a minimum in order to give a concise picture of the capabilities of the interceptor system. The results of the two years work have been reviewed, but emphasis has been placed on more recent work. The salient points are:

(a) The system has high interception capabilities against a Subsonic target at 50,000 ft. altitude.

(b) The system has high placement probability against a non-manoeuvering Mach 2.0 target at 60,000 ft. altitude.

(c) Snap-up attacks from 40,000 ft. altitude increase placement probability at course difference greater than 120°.

(d) Climbing attacks from 40,000 ft. altitude increase placement probability at course difference less than 110°.

(e) Under E.C.M. conditions placement probability can be high if properly instrumented passive homing methods are used.

(f) Lock-on should not be made until 20 n.m. range so that the bomber will not be warned to take evasive action.

A thumb nail sketch of the main features of the study are given in the captions at the bottom of pages throughout the report.

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SUMMARY REPORT II

1.0 INTRODUCTION

This report summarizes the results of the Assessment Study of the Arrow interceptor system which was carried on at CARDE over a two-year period, May 1957 - February 1958. The study was mainly concerned with the AI phase of the attack. The accuracy of vectoring entered as a parameter and some critique was made of the effect of weapon performance and final impact. The portion of the overall attack which was considered is shown by the doubled lined blocks in Figure 1.

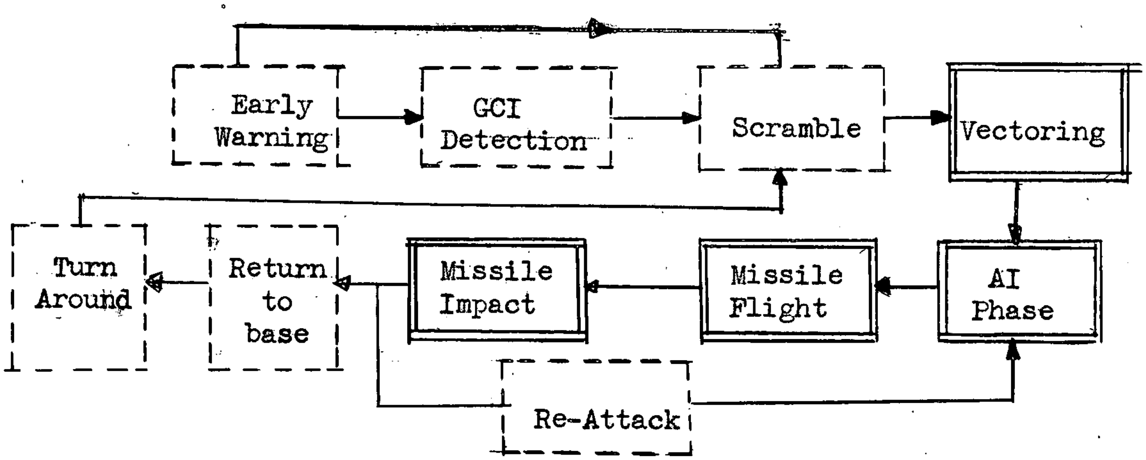

FIGURE I. Phases of an Interception

The overall statement of system effectiveness is expressed in terms of probability. The probability of successful interception may be written symbolically as

$$P = P_D \times P_P \times P_S \times P_K \times R \times P_J$$

THE CARDE ASSESSMENT WAS A STUDY OF THE AI PHASE OF THE ATTACK.

Where

P_D = probability of detection and tracking of the threat by the ground environment

P_P = probability of successful positioning of the interceptor

P_S = probability of survival of the aircraft until missile launch

P_K = lethality or kill probability of the weapon system

R = reliability of the system

P_J = probability that the system will not be degraded due to electronic countermeasures.

The main effort of the CARDE study has been directed towards evaluation of P_P for ranges of the numerous parameters that influence this factor. Considerable effort has also been directed to a better understanding of P_J. Brief mention only was made of P_K and R. The ground environment capability enters only as a parameter and is introduced in terms of the accuracy of vectoring of the interceptor against the threat.

2.0 ASSUMPTIONS

Work at CARDE has proceeded within the framework of the following situation:

(a) One interceptor against one bomber.

(b) High altitude targets (above 35,000 ft.)

The case of one interceptor against one bomber was chosen primarily because of ease of computation. Before the multi-aircraft situation can be studied, the case of one against one must be known in some detail. Conclusions concerning required parameter values in many tactical situations are valid for the multi-aircraft case.

The prime role of the Arrow is high speed, high altitude interception. Attention has therefore been concentrated on targets above 35,000 ft. Because of time limitations consideration has not been given to low altitude threats.

The AI phase was chosen for special study because it may be regarded as the pivotal portion of the attack. On one hand, it is influenced by the accuracy of the vectoring phase as dictated by the

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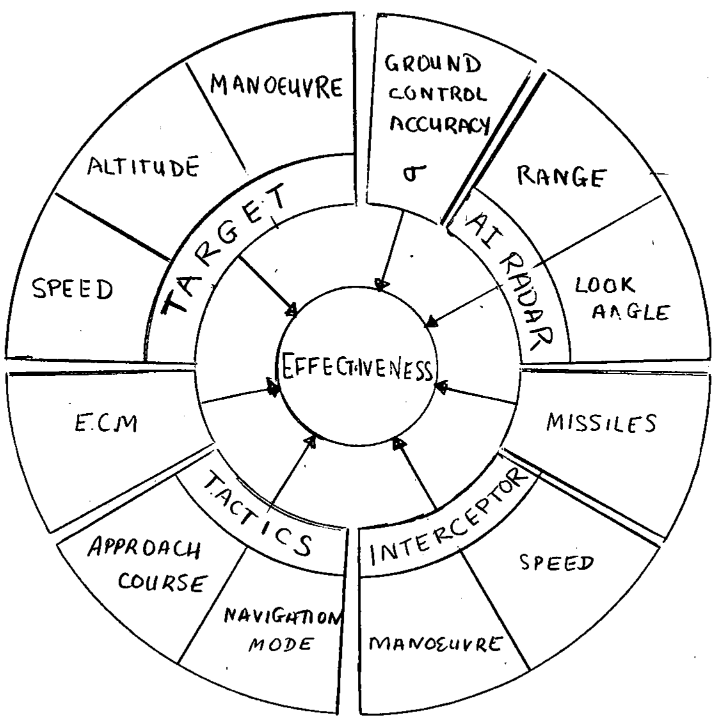
BASIC ASSUMPTIONS: HIGH ALTITUDE, HIGH SPEED, ONE AGAINST ONE.

ground environment, and on the other hand, the requirements of placement are defined by the weapon launch range and allowable heading errors.

Both subsonic and supersonic targets have been considered. The subsonic target was assumed to be either the Bison or the Bear. No specific Soviet supersonic bomber has been reported, but two hypothetical Mach 2 configurations were studied.

3.0 PARAMETERS

Figure 2 is a representation of the many parameters which enter into the study of interceptor placement. The parameters are arranged in a circle to stress the fact that no one factor can be considered by itself, and that the value of one parameter influences those required of all the others, in order to obtain a desired system effectiveness. Statements in this report must therefore take a conditional form: if certain parameters have given values, certain conclusions can be stated. Where possible expected values of the parameters are indicated. However, in most cases a range of values was chosen so that if the situation changes, the results of the study are not invalidated. This method of procedure indicates the sensitive and critical parameters of the system.



4.0 TERMINOLOGY

Several special terms are used in this report.

1. S - Specification AI range. The RCAF specification calls for a 25 n.m. range on a 5 m^2 target at the 80% level of probable detection. Detection ranges on targets using these figures as basis are called specification range (or 1.0S). Degradation from the value are given as fractions of S. (.4S, .6S, etc.) Acquisition range is that range at which the AI radar, after detection of the target, may be locked on to it so as to provide steering instructions. In a track-while-scan or manual tracking mode, it would be defined as that range at which steering instructions can commence, after detection of the target. It has been assumed in this study that the median value of acquisition range is equivalent to the range for 80% probability of detection.

   Because radar cross section varies little for some 30° depression angle on the nose of an aircraft, the same acquisition ranges were used for differential altitude cases.

2. σ - Standard deviation of ground vectoring error. It is measured normal to the ideal approach path and stated in nautical miles.

3. τ - Course difference. Angle between fighter and target velocity vectors such that for tail-on attack $\tau = 0°$, and head-on, $\tau = 180°$.

4. Delta - Supersonic Bomber Delta configuration giving 34 n.m. acquisition range on nose.

5. Straight Wing - Supersonic Bomber. Giving 21 n.m. acquisition range on the nose. (Roughly equivalent to .6S of Delta).

6. Δh - Altitude differential between target and fighter at acquisition. Measured in thousands of feet.

7. P_P - Placement Probability. The chance that the interceptor after AI detection can complete a successful weapon launch.

SPECIAL SYMBOLS ARE DEFINED.

5.0 VARIATION OF PARAMETERS

The principal parameters which were varied over wide ranges in the assessment were the AI radar range and the ground vectoring accuracy. The effects of these variations are discussed in this section.

5.1 Relation of P_p to AI Range Performance, Non-Evading Targets

Against a non-evading target, probability of interceptor placement always increases with increasing AI range, and for a large enough range, becomes 100%. Figure 3 shows a typical graph of P_p as a function of R.

Usually the curve starts with a very steep slope, followed by a knee, and then a "plateau" or gradual increase to some maximum value. This maximum will always be 100% if the average ground control error σ is less than 5 miles. The position of the knee on the curve is important, since in general, probabilities are good above the knee, but critical below.

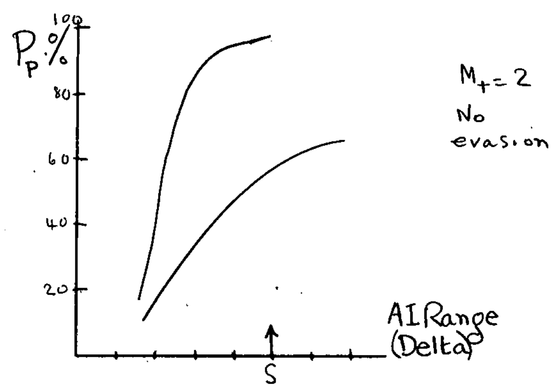


Fig. 3. Typical P_p/R Curves.

For values of σ below 5 n.m., the knee occurs between 0.4S and 0.7S for the Delta contour, and between 0.5S and 0.9S for the straight wing target. For these values of σ also the probability at the knee is above 70% for beam attacks and above 85% for head-on attacks. These results are illustrated in Figures 4 and 5 below.

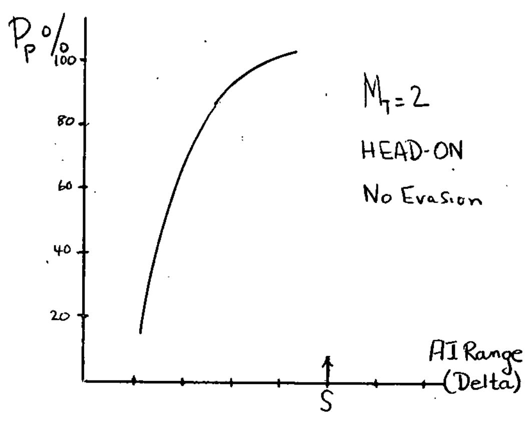


Fig. 4

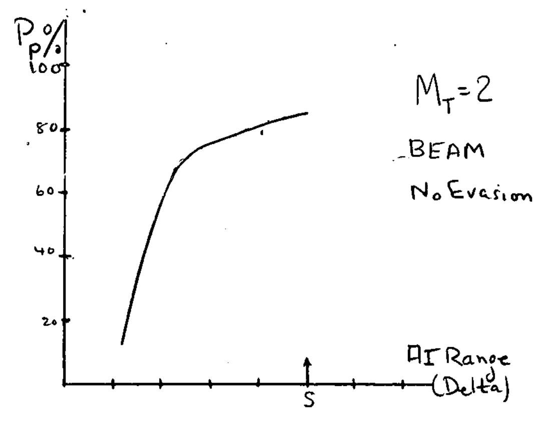


Fig. 5

P_p/R Relationships for Non-Evading Targets.

INTERCEPTOR EFFECTIVENESS IS EXPRESSED IN TERMS OF PLACEMENT PROBABILITY.

5.2 Relation of P_p to AI Range Performance, Evading Targets

The effect of target evasion on the placement zone is discussed in Section 8. If the target evades intelligently, and if the interceptor tracks intelligently, the same general functional relationship between P_p and R is true. A typical P_p graph for the evading case is given in Figure 6. The knee is less pronounced in general, and the plateau occurs at a lower value of P_p, and at higher values of AI range.

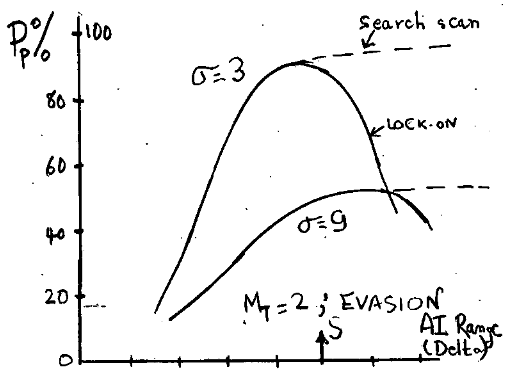


Fig.6. Typical P_p/R Curves

For values of σ below 5 n.m., the knee occurs between 0.5 and 0.9S for the delta target, and between 0.7 and 1.2S for the straight wing target. The probability at the knee is about 50% for beam attacks and 85% for head-on attacks. These results are illustrated in Figures 7 and 8 below.

If the evasion begins soon after lock-on, the degradation caused is greater when lock-on occurs at long ranges. This drop is prevented if initial course corrections are made while the interceptor is in the search mode, so that warning will not be given to the bomber at long range.

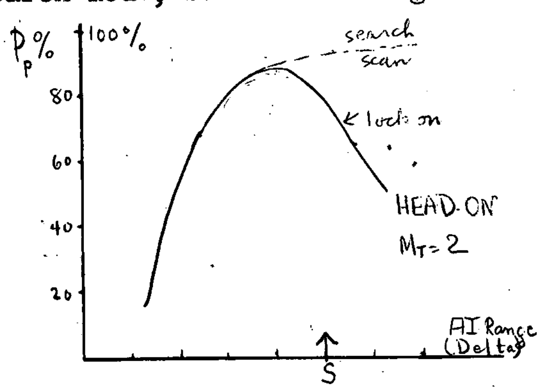


Fig. 7.

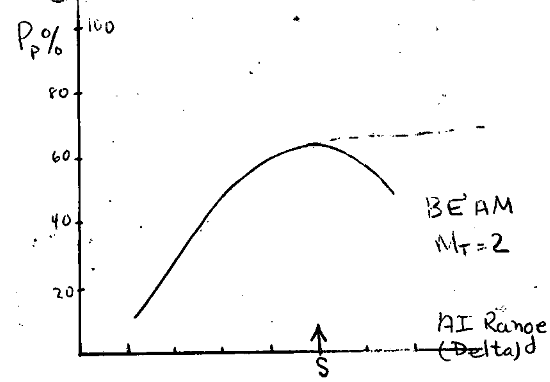


Fig. 8

P_p/R Relationships for Evading Targets.

THE INTERCEPTOR SHOULD EXPECT INTELLIGENT TARGET EVASION.

5.3 Variation of P_p with σ

As would be expected, the placement probability improves with GCI accuracy (i.e. as σ becomes smaller). Low σ values mean that the interceptor can be placed close to the ideal line, so that if this line lies between the front and rear placement barriers, high placement probability results.

The graphs of Figures 9 and 10 illustrate the dependence of positioning probability on ground control accuracy for two typical cases, a beam attack and a head-on attack. These results are for an evading target, where it is assumed that the AI is operated in the search mode to 20 n.m. range, but with corrective turn started at the range indicated in the curves.

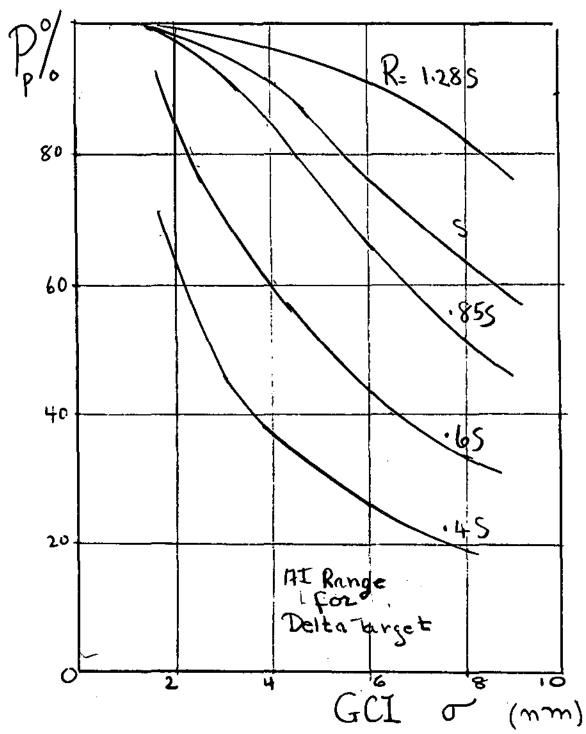


Fig. 9. Beam Attack

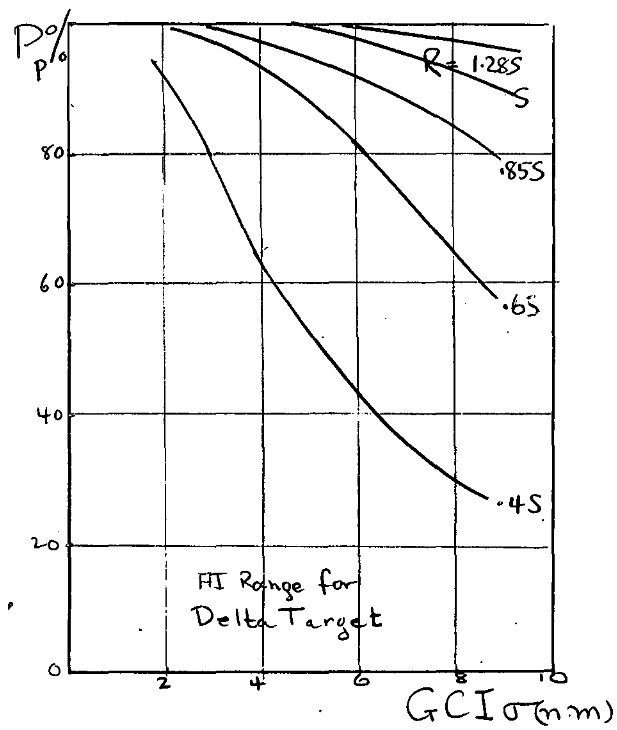


Fig. 10. Head-on Attack

Variation of Placement Probability with GCI Accuracy. Mach 2 Evading Target.

EXPECTED σ: CLEAR SITUATION 1.5 n.m.,
ECM SITUATION 3 n.m.

For head-on attacks, if AI range is very good (.85S for delta target, or 1.4S for the straight wing) the value of σ is not important. However, for smaller values of AI range, the probability falls off seriously with decreasing GCI accuracy.

For beam attacks, a low value of σ is required even if the AI performance is very good.

5.4 Probable Values of σ

Information supplied by DSE indicates that with a SAGE environment and no ECM, a vectoring error measured normal to the attempted approach path of 1.5 n.m. may be achieved. Under ECM conditions, if good angle information is available, vectoring may be accomplished to within 3 n.m. In the case when the ground environment cannot supply angle information, the fighters have to proceed under broadcast control being given only the general direction and heading of the threat. While largest vectoring error investigated in the CARDE study was 9 n.m, this is not to be taken as any indication of the accuracy to be expected under broadcast control.

5.5 Desired Placement Probability

The various probabilities that must be taken into account in determining overall interception potential are discussed in Section 1. In order to get an acceptable overall effectiveness, all these probabilities must be high. As a working criterion it is generally taken in this study that a placement probability of 95% is required.

6.0 RESULTS FOR THE BASIC CASE

A basic case which was chosen for analysis was the interception by the Mach 2 interceptor of a Mach 2 delta target at 60K ft. The capability of the Arrow system in this case will be reviewed, and the effects of altitude and speed variations will then be discussed. Table I below summarizes the placement probability for this case for three values of σ, with and without ECM, and with no target evasion. The table gives values for co-altitude attacks, and for snap-up attacks from 40K ft.

BASIC CASE: MACH 2 DELTA TARGET AT 60K FT. ----------
REQUIRED P_p = 95%

TABLE I

Placement Results in the Basic Case

Course Difference	$\sigma = 1.5$		$\sigma = 3.0$		$\sigma = 9.0$		Barrage Jamming	Spot Jamming
	P_p	Allowable AI Deg.	P_p	Allowable AI Deg.	P_p	Allowable AI Deg.		
180°	100%	50% 60%SU	100%	30% 40%SU	89% 96%SU	—	50% $\sigma = 1.5$ 30% $\sigma = 3.0$	0%
135°	100%	50% 60%SU	100%	0% 40%SU	82% 84%SU	—	60% =1.5 40% =3.0	0%
110°	100%	35% 60%SU	96% 99%SU	—	71% 81%SU	—	60%SU =1.5 50%SU = 3.	0%

The figures quoted in the main column of the Table are for unjammed AI radar. The degradation allowable for the value of P_p shown may be due to mild ECM, equipment deterioration, or low value of target radar cross-section.

The jamming cases refer to jamming of the AI radar, of the type described in reference 1. The figures given for the jammed case are for co-altitude attacks. For snap-up attacks probability is generally smaller because the minimum detection range required for successful positioning is greater for the differential altitude case. The chance of success in the jammed case is estimated here only on the basis of crossover range. Techniques for improving the situation are discussed in Section 10.

IN BASIC CASE WITH NO EVASION, NO E.C.M., $P_p \sim 100\%$

Wherever allowable degradation is greater than 40%, the figures for P_p would also hold for the straight wing target. Some additional cases for this target are summarized in Table II.

TABLE II

Straight Wing Target.

Course Difference	$\sigma = 3.0$ P_p	$\sigma = 9.0$ P_p
180°		53% 80% SU
135°		50% 73% SU
110°	86% 97% SU	45% 68% SU

Conclusions - Basic case, no evasion.

1. Provided the AI and the ground environment function, ($\sigma = 3$ n.m.) the interceptor system is capable of intercepting the basic threat with a high placement probability (greater than 95%).
2. Attacks may be made with course differences from 180° to 110°.
3. The target may be either Delta or straight wing.
4. Under jamming of the AI, it is better to approach for co-altitude attack.
5. Under jamming, the system has an unacceptable placement probability, if only crossover techniques are used.
6. Under poorest AI conditions ($\sigma = 9.0$) acceptable placement is accomplished only by snap-up from head-on attacks.

FOR STRAIGHT WING TARGET $P_p \sim 100\%$ FOR GOOD σ

6.1 Effect of Course Difference in Basic Case

If a placement probability of 95% is required, the permissible course difference are summarized in the following Table:

TABLE III

Values of Course Difference Giving $P_p = 95\%$

σ	Climbing Attack from 40K ft.	Snap-up Attack from 40K ft.	Co-altitude Attack
3 n.m.	$180^\circ - 120^\circ$	$180^\circ - 115^\circ$	$180^\circ - 110^\circ$
9 n.m.	-	$180^\circ - 150^\circ$	-

In a climbing attack at $\sigma = 9$ n.m., the P_p never rises above 92%. For $\Gamma = 145^\circ$, P_p is between 85% and 92%. Generally, satisfactory results cannot be obtained with a course difference of less than 110°. If a very small course difference (75°) must be used, then a σ of 1.5 n.m. is required and a snap-up attack from 40K ft. must be made.

6.2 Effect of Increase in Target Altitude

In studying high altitude and high speed targets, the assumption was made that the Arrow would be armed with a weapon whose heading error, launch range, and time of flight characteristics were equivalent to those of Sparrow II at 50,000 ft. It must be stressed that it is not known whether such a weapon exists. The results given below only indicate the potential of the interceptor if it can be equipped with such a missile.

Table IV below summarizes the cases where placement probability is greater than 95%, for a Mach 2 target flying at 70,000 ft, and the Arrow intercepts by climbing from initial speed of Mach 2 at 50,000 ft.

TABLE IV

Target At 70K ft; Climbing Attack from 50K ft.

Course Difference	$\sigma = 1.5$		$\sigma = 4.75$		$\sigma = 9.0$	
	P_p	Allowable AI Deg.	P_p	Allowable AI Deg.	P_p	Allowable AI Deg.
180°	95%	40%	95%	0%	71%	-
135°	95%	40%	95%	0%	68%	-
110°	95%	40%	-	-	-	-

PREFERABLE COURSE DIFFERENCE 120° TO 180°

It should be noted that the cases illustrated are for attacks from 50K ft., that is an altitude difference of 20K ft. In this case snap-up gives poorer results than climbing. The drop in P_p may be of the order of 25% to 40% absolute for the snap-up case. However, if the fighter starts at 40K ft. snap-up is quite acceptable. Generally, if $P_p \geqslant$ 95% for 60K ft. target, then it will also be $\geqslant$ 95% for a 70K target. However, much less degradation in AI range is permitted (about 15% for head-on case).

Invariably it may be said that if conditions are unfavourable at 60K ft. then the increase in target altitude has a much worse effect than if the conditions were favourable.

Conclusions

1. Under favourable conditions large Mach 2 targets at 70K ft. can be intercepted.

2. If AI range is less than that for the delta target, placement will be considerably degraded unless σ is good.

3. If an attack is to be made under marginal conditions of target speed and altitude, ground control judgment of target altitude is critical.

4. A brief set of rules may be given for attack on the 70K ft. target:

   (a) if fighter is at 60K - climb

   (b) if fighter is at 50K - climb

   (c) if fighter is at 40K - snap-up

   (d) if Γ is less than 110° - always climb

This bears out RCA's rules to climb if Δh is less than 30K ft. and to snap-up if Δh is greater than 30K ft. CARDE's work indicates that snap-up is usually better, but in cases where Δh is small the difference is negligible.

6.3 Target at Lower Altitude

Targets flying at lower altitudes than the basic 60K ft. allow a better probability of placement. Values are given in

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FOR Γ LESS THAN 110°, ALWAYS MAKE CLIMBING ATTACK

Table V for equal speed, co-altitude attacks on a Mach 2 target at 50K ft.

TABLE V

Co-Altitude at 50K ft.

Course Difference	$\sigma = 1.5$ P_p	$\sigma = 1.5$ Allowable AI Deg.	$\sigma = 3.0$ P_p	$\sigma = 3.0$ Allowable AI Deg.	$\sigma = 9.0$ P_p	$\sigma = 9.0$ Allowable AI Deg.
180°	100%	55%	100%	40%	93%	
135°	100%	55%	100%	5%	90%	
110°	100%	40%	96%		88%	

For course differences of 180° to 135° placement chance under barrage jamming of the AI, using only crossover information, is about 50%.

Similar results are obtained for co-altitude, equal speed attacks on a Mach 2 target at 40K ft. Generally some 5% more AI degradation is allowable.

6.4 Higher Speed Target

For attack on a Mach 3.5 target at 70K ft., the conditions for satisfactory placement are more restrictive. They are summarized in the following Table. Results are essentially the same for climbing and snap-up attacks.

TABLE VI

Conditions for $P_p \geq 95\%$, (High Speed, High Altitude)

Course Difference	Specification AI Range Δh = 10K ft.	Specification AI Range Δh = 30K ft.
180°	$\sigma = 1.5 - 3$	$\sigma = 1.5 - 3.5$
135°	$\sigma = 1.5 - 2$	$\sigma = 1.5 - 2.5$

In general, if the placement probability is high (near 100%) for a Mach 2 target, then the degradation is relatively small for

SYSTEM IS EFFECTIVE AGAINST A MACH 3.5 TARGET IF HEAD ON ATTACK IS USED.

increasing the speed to Mach 3.5 (0 to 15% Abs.) When P_p is poor (75 to 80%) for Mach 2, then degradation is much more severe for a Mach 3.5 target, (it may be of the order of 30%).

The above figures are those for specification AI performance on the delta target. If the AI is degraded, or target radar cross-section small, the situation is more critical. If vectoring accuracy is 1.5 n.m., and AI range is .6S, P_p is 90%, but drops rapidly to zero at .5S. Thus if the AI is somewhat below specification and the target is small, there is practically no placement chance.

Conclusions, for M 3.5, 70K Target.

1. Good vectoring accuracy is required.
2. Attack should be as near head-on as possible.
3. AI range must be at least specification.
4. There must be a weapon which works at these altitudes.
5. Better results are obtained from initial fighter altitude of 40K ft.
6. For $\Gamma = 180^\circ$ it is better to snap-up, but for $\Gamma = 135^\circ$ it is better to climb.

6.5 Very High Altitude Targets

Some consideration was given to a Mach 3.5 target flying at 80K ft. The requirements for obtaining P_p of 95% are even more stringent in this case, as Table VII below shows:

TABLE VII

Conditions for 95% P_p for 80K ft. M 3.5 Target

σ	Minimum AI Range	Course Difference	
1.5	.65S	165	180°
4.75	.9S	175	180°
6.75	1.30S	180°	

If the course difference is reduced to 135°, placement chance of 95% cannot be achieved. For specification AI range on a delta

TARGET AT 70K FT. OR HIGHER MUST BE ATTACKED FROM 40K FT.

target, P_p ranges from 85% at σ of 1.5 to 60% at 4.75 and 40% at 9.

These results are for snap-up attacks from 40K ft. Climbing attacks from 40K ft. are definitely inferior to snap-up in this case, since range at which the climb may begin is very critical.

Conclusions for M 3.5 80K ft. Target

1. Within a very restricted set of conditions placement may be accomplished.
2. Snap-up attacks must be used, with pull-up from 40K ft.
3. For targets of smaller radar cross-section than the delta, P_p may be unsatisfactorily low.
4. Any evasion would highly degrade the situation.

6.6 Lower Interceptor Speed

If the basic target (Mach 2 at 60,000 ft) is attacked by the Arrow with Mach 1.5 initial speed only, a definite degradation in placement chance is incurred. For 95% placement probability the following circumstances are required:

$\sigma = 1.5$
AI range .6S or better.
Course difference 180° to 110°

In this situation differential altitude is harmful. As Δh increases the AI range value which gives essentially zero placement chance increases. For h = 20K ft. and $\Gamma = 180^\circ$ it is 1.2S.

If course difference is 110°, commencing manoeuvre at an extremely long range will lower the placement chance since loss of speed in the turn makes the fighter fall too far behind.

6.7 Lower Target Speed

If the Mach 2 interceptor makes a co-altitude attack on a Mach 1.5 target at 60K ft., placement chance is improved for

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AGAINST M2 TARGET, TRY TO HAVE INTERCEPTOR AT M2 BEFORE MANOEUVRING.

smaller course differences. Table VIII below summarizes the situation.

TABLE VIII

M 2 Interceptor vs M 1.5 Target

Course Difference	$\sigma = 4.75$	$\sigma = 9.0$
$180^{\circ} - 135^{\circ}$	$P_p = 100\%$	$P_p \geqslant 95\%$
110°	100%	90 - 95%
75°	95%	95%

7.0 THE USE OF DIFFERENTIAL ALTITUDE ATTACKS

For a Mach 2 target at 60K ft., the probability of placement for the Mach 2 Arrow is as good (or better) for differential altitude attacks as for co-altitude attacks. For specification AI range on the delta target the gain is slight at forward aspects, but when the AI is degraded to .5 of specification, an absolute gain of 10% may be obtained. Increases in beam attacks are even more striking. For example, when $\Gamma = 75^{\circ}$ and $\sigma = 1.5$ P_p is 69% for a co-altitude attack, and 98% in a climbing attack from 40K ft.

Two types of differential altitude attacks were considered. In the climbing attack the interceptor corrects errors in azimuth and elevation simultaneously; in a snap-up attack the interceptor remains at its lower altitude while the azimuth error is being corrected, finally snapping up only to launch its missile. In most cases snap-up attack gives better probability of successful placement than does climbing attack. The increase in probability over the co-altitude case is not as dependent on AI range capability as in the climbing case. For snap-up, improvement can be expected from specification range down to .4S. For climb, improvement is greatest if manoeuvre starts at about .6S, and less for greater and lesser AI ranges. Figure 11 illustrates how the improvement in P_p varies with AI range capability for climbing and snap-up attacks. Figure 12 shows how the improvement in P_p for snap-up attack varies for two different values of σ.

BEST INTERCEPTOR OPERATIONAL ALTITUDE IS 40,000 FT.

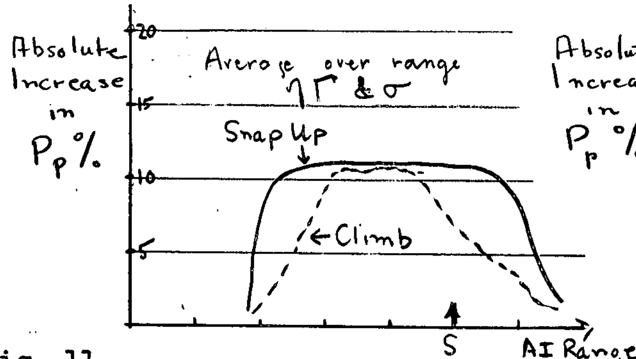

Fig. 11

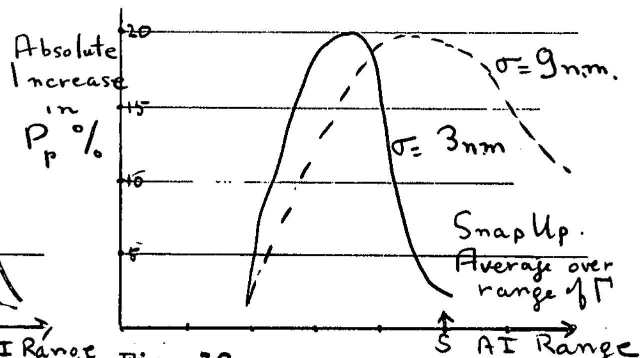

Fig. 12

Improvement Obtained by Using Differential Altitude Attacks.

Implementation of a snap-up attack requires knowledge of the proper time to snap the interceptor up to the required launch elevation. It was found that the requirement is not too critical. The time chosen was 20% greater than the time-to-go corresponding to the minimum successful range for the climbing attack. This time-to-go varies with the launch requirement of the missile, speed and altitude of the interceptor, and altitude of the target. It is independent of initial course difference between interceptor and target.

Satisfactory time-to-go-to-impact for snap-up was found to be 20 seconds for interceptor altitude 40K ft., and 16 seconds at 50K ft, against a 60K ft. target. For the 70K ft. target, the time was 30 seconds for 40K ft. interceptor altitude.

Conclusions

1. Differential altitude attacks from 40K ft. with the Mach 2 Arrow are always preferred to a co-altitude attack on a 60K ft. Mach 2 target.
2. For cases of most interest (σ = 1.5 to 3) there is no difference between results for climb and snap-up, except for very short AI range (.5S)
3. In general, it is better to use snap-up if Γ is greater than 110°, and climb if Γ is less than 110°.

SNAP-UP IF $\Gamma > 110^\circ$; CLIMB IF $\Gamma < 110^\circ$.

8.0 TARGET EVASION

It has been shown in this study that evasive manoeuvre by the bomber is extremely effective in reducing the probability of interceptor placement. In this section the effect of target evasion on the differential altitude attack is considered.

A target evasion of .75 lateral g's was assumed, beginning shortly after the bomber was continuously illuminated by the AI. It was assumed that the bomber was equipped with a passive device permitting rough angle tracking, so that the direction of the evasive turn could be optimized. The general results are summarized in TABLE IX below.

TABLE IX

Evading Mach 2 Target at 60K ft. Snap-up Attack

Course Difference	P_p for $\sigma = 1.5$	P_p for $\sigma = 3.0$	P_p for $\sigma = 9.0$
180°	100% for AI .5S to S.	100% for AI .85S to S	65%
135°	0 at S 100% at .5S	5% at S 85% at .55S	25% at S 47% at .6S
110°	0 at S 78% at .5S	0 at S 65% at .5S	0 at S 35% at .6S

Although these results were obtained with .75 g's lateral target evasion, a manoeuvre of .3 g's is sufficient to degrade the placement probability appreciably. The effect which has been noted in Section 5, where evasion degrades the attack more for long AI acquisition range, is apparent in these results.

8.1 Comparison of Attack Types for Evading Targets

The extent to which differential altitude improves placement probability for an evading target depends strongly on attack course difference. The effects are summarized in the following Table.

HEAD-ON ATTACKS ARE LEAST DEGRADED BY EVASION.

TABLE X

Comparison of Various Types of Attack for Evading Target

Course Difference	Effect
180°	Snap-up from 10K is 10% better than co-altitude; climb, 5%. Snap-up from 20K is 15% better than co-altitude; climb, 5%.
135°	Results for snap-up, climb, and co-altitude are equal, unless $\Delta h > 20K$, when snap-up is better.
110°	Climb from Δh = 10K ft. is 10% worse than co-altitude, and snap-up 20% worse. Climb from Δh = 20K ft. is as good as co-altitude, and snap-up 15% worse.

8.2 Corrective Measures

The evasion described above can reduce P_p to zero and is particularly effective at long AI acquisition ranges. It could be completely countered by leaving the AI on search until 20 miles range, with the navigator making approximate heading corrections for gross positioning errors. (This procedure has been proved practicable in project Sprint trials). These corrections require the navigator to have an approximate knowledge of bomber heading and air speed. Neither of these items are included in the SAGE close control message form as it now exists.

In the case where evasion of the type described takes place, a displacement of the ideal approach line, such that the aircraft homes on a point ahead of the target, tends to increase P_p, since this places the line nearer the centre of the placement zone. The maximum probability attained is increased by about 5 to 8% absolute. However, the greatest advantage comes from the fact that this maximum P_p is maintained over a much wider band of AI ranges. (See Figure 13).

These trends hold for either co-altitude or differential attack. However, the displacement of the ideal line required is much greater in differential altitude than for h = 0. (See Figure 14).

DO NOT HAND TRACK OR LOCK ON UNTIL 20 N.M.

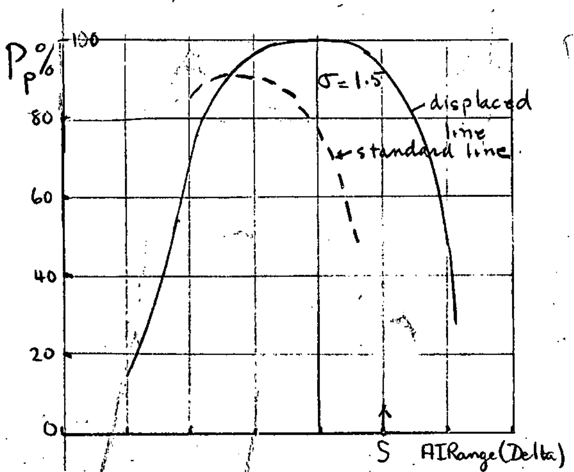

Fig. 13 Effect of Forward Displacement of Approach Line.

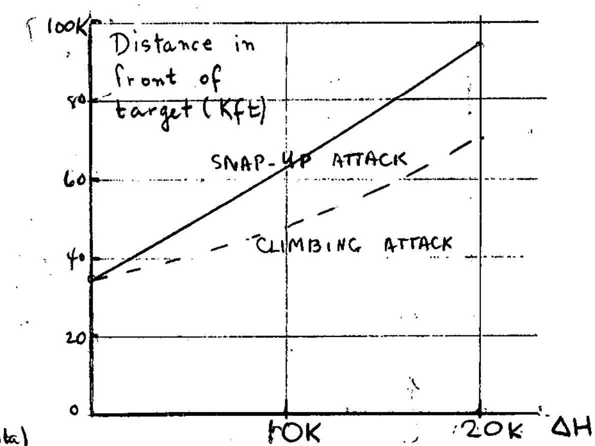

Fig. 14 Optimum Attempted Interception Point.

It has been shown that a very mild target evasion is very effective in reducing placement chance, unless corrective measures are taken. Using the manoeuvre considered here the target will have turned 60° off course between initiation of manoeuvre and weapon launch. Present day bomber navigation instruments should be able to permit such tactics.

Conclusions

1. Target evasion could seriously degrade the system.

2. Attacks should be made with course difference as near 180° as possible.

3. Lock-on or hand-track should not start until 20 n.m. range.

4. Consideration should be given to vectoring to a point ahead of the target.

9.0 SUBSONIC BOMBER TARGET

Most work in this study was concerned with supersonic targets, not because this was the major threat, but because this case demands the highest performance from the system and was heretofore least understood. The Arrow has high intercept capabilities against subsonic targets such as Bear or Bison. If the fighter is used with a speed advantage, placement probability is essentially 100%. If the target manoeuvres, interception is possible

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VECTOR INTERCEPTOR AHEAD OF THE TARGET.

with a speed advantage in all cases, provided interceptor speed is not too high. Certain complex manoeuvres may require the interceptor to slow down almost to target speed and take up a tail chase. This may produce large penetration, but should not prevent interception.

Even if the Arrow is used at subsonic speed, placement probability against the equal-speed bomber is 95% in all cases, except for $\sigma = 9$ n.m., when P_p is 92%.

Under ECM conditions, tactics described in Section 10 are even more effective against subsonic targets than against supersonic bombers.

10.0 ECM STUDIES

It is considered that ECM will be used by the enemy against ground and airborne radars in nearly all attacks, and that operation of the AI in a clear environment is unlikely. Optimizations of the weapon system must be carried out with this in mind.

10.1 Crossover Range Study

The initial study of the ECM problem involved the assumption that no corrective manoeuvres would be executed by the fighter until crossover occurred (i.e. until the radar return was feasible above the jamming signal). The probability of successful placement under this assumption is approximately 40% against a barrage jammer, and zero against a successful spot jammer. However, the assumption that corrections are initiated only at crossover represents an inefficient use of the weapon system, since angular information is available as a basis for corrective action long before crossover occurs. This led to the study of ECM homing on the basis of angular information only.

10.2 Minimum Information Study

This study was concerned with AI homing and launch ranging against a single jammer, assuming no range information was available from the radar, but that angular information was available either in the search mode or from passive angle tracking. Five different homing methods were assumed:-

1. Pure pursuit
2. Fixed lead pursuit
3. Pure collision
4. Fixed line of sight rate collision
5. Fixed range lead pursuit

FOR SUBSONIC TARGET KEEP FIGHTER AT A SLIGHT SPEED ADVANTAGE.

The most useful course was found to be No. 5, which utilizes the lead pursuit equation in which range is fixed at a value corresponding to the average missile launch range. With this mode it is possible to achieve correct missile launch heading within 5° on targets travelling at speeds up to Mach 2, whose speed and direction is unknown to the attacker. The residual launch zone within which this course satisfies missile launch requirements is almost identical with the unjammed missile launch zone.

In addition to the provision of an AI homing capability, it is necessary to devise passive means of determining when to launch the missile. Seven passive ranging methods were considered:-

1. Visual
2. Telescopic
3. G.C.I.
4. IR
5. Oscillating range finding manoeuvres

   (These methods tend to provide a fixed range for launch).

6. Jammer power and power rate measurements
7. Line of sight rate and rate of change of rate.

   (These provide a measure of $R/\dot{R}$ - pseudo time-to-go.)

Methods 5 and 6 appeared the most promising. It is estimated that the RMS error in range or time-to-go determination will lie between 20% and 60%.

Using these preferred homing and ranging methods, the combined probability of successful placement and launch ranging is shown in the following Table:

TABLE XI

Probability of Placement and Ranging VS
Non-Manoeuvering Mach 1.5 Jammer.
(GCI σ = 3 n.m.)

Homing/Ranging Methods (% Ranging Accuracy)	$\Gamma = 110^{\circ}$	$\Gamma = 180^{\circ}$
5/5 (20%)	93	93
5/5 (60%)	40	55
5/6 (20%)	75	85
5/6 (60%)	30	45

UNDER ECM CONDITIONS $P_p > 90^{\circ}$ USING FIXED RANGE LEAD PURSUIT PASSIVE HOMING.

Notes:

1. These figures assume that the missile seeker is capable of independent range search when lowered from the armament bay.

2. Homing method 5 requires successful angle tracking and the addition of one relay and one potentiometer to the fire control circuits. If passive tracking cannot be achieved, and homing must be accomplished by the navigator from AI search information, the best homing procedures appear to be a combination of methods 1 and 2.

3. If launch ranging can be accomplished by crossover, the figures in the above Table are increased to within a few percent of the non-jammed values.

4. The probability of placement and ranging for the MB-1 is less than 10%, due to its inability to tolerate launch heading and ranging errors. Hence this missile is least useful in the most likely tactical situation.

5. P_pP_R for subsonic targets is higher than the values given here for supersonic targets.

6. If the IR system is used for angle tracking results are not as good. Obscuration of the detector by the aircraft in certain situations cuts down the placement zone, and head-on IR detection range is thought to be very small.

10.3 Multiple Target Situations

With jammer spacings of one to two miles, passive AI angle tracking at useful ranges will be impossible. However, raid size estimates given by Intelligence have recently been revised downward, and a raid of up to fifty aircraft will be reasonably well defined in AI search. Hence the navigator should be able to execute homing methods Nos. 1 and 2. Passive ranging methods 1, 2, 3, and possibly 4 and 6 are applicable, with some loss in accuracy. Placement and launch probabilities are believed to be in the order of 40%.

At present the IR seeker has a beam width of 2° and its potential for accurate angular discrimination is not being utilized. The use of fractional degree IR beam widths would greatly improve system performance against multiple jammers.

PLACEMENT FOR MB-1 UNDER ECM CONDITIONS IS POOR.

10.4 Capability of Presently Planned Astra I Equipment Against Electronic Jamming.

The preceding remarks are a report on a feasibility study of certain ECCM equipment and tactics. However, some of the figures of Table 1 assume the use of certain devices not presently planned for the Astra I system. It is believed that initial squadron Astras will incorporate a true collision/fixed range lead pursuit homing-mode, but no passive ranging equipment. Hence, the present system must obtain range by ranging methods 1 or 3, or by crossover. It is believed that by the time the Astra system reaches the squadrons, enemy jammer developments will have produced barrage jamming power densities which will deny the interceptor any useful crossover range. The usefulness of ranging methods 1 and 3 is difficult to estimate, since it depends on enemy tactics, and possible improvements in North American GCI radars. It is likely that the Table 1 figures for 60% launch range error will apply.

The variable polarization feature of the present Astra system is believed to be ineffective for the following reasons:

1. Jammers can be made omnipolar with only slight loss in power output.

2. Angular errors of up to one beam width will occur when the Astra attempts to passive track the cross-polarized component of jammer radiation, since the antenna gain pattern and discriminator pattern for cross-polarized signals are the inverse of the patterns for signals of the same polarization. This condition is unavoidable in the present system whenever the jammer is plane polarized, since only two choices of plane polarization are available, and the polarization plane is not space stabilized.

The Quasi-passive ranging mode presently scheduled for Astra I is effective only against spot jammers which have relatively slow tuning rates. Present development in the USA and France of tubes and circuits capable of pulse-to-pulse tuning indicates that the useful lifetime of this ECCM mode will be relatively short.

In general, emphasis should be placed on passive homing and ranging methods rather than active CCMs, since the former are much less subject to obsolescence.

10.5 Chaff

The usefulness of chaff has been greatly increased by the development of aluminized nylon and glass fibres and the use of forward firing dispensers. Russian progress is assumed to parallel our own.

PASSIVE HOMING AND RANGING TECHNIQUES ARE BEST FOR CCM.

Accurate prediction of Astra I performance against break-lock chaff is extremely difficult, and the range-tracking parameters of Astra are not yet fixed. Approximate analysis indicates that gravity launched chaff released by supersonic bomber will break lock in a 15° region centered on the bomber's beam aspect.

If the chaff is forward-fired so as to blossom around the bomber, break lock will occur in a 30° zone on the target's beam. The degradation of P_p caused by this vulnerable zone is only a few percent for head-on attacks (and tail attacks if speed ratio allows). For attacks at 110° course difference placement probability is approximately halved and at 75° it is reduced to 1/4 of the non-chaff value.

If a series of chaff bursts are sown by a chaff rocket out to several hundred feet ahead of the target, break lock is expected to occur at all target aspects.

It is relatively easy for the lead aircraft of a bomber formation to lay a wide corridor of chaff within which other bombers will be effectively screened from pulsed AI's. However, it is still possible to attack the lead aircraft of the formation.

10.6 Aircrew Training in ECCM Techniques

It is possible with very slight additions to the normal radar circuitry to simulate ECM effects in a radar which is actually locked on to a non-jamming target. These devices should be incorporated in all squadron aircraft and the majority of practice interceptions should be carried out in a simulated ECM environment.

11.0 LETHALITY OF SPARROW MISSILE

Assessment of the lethality of an air-to-air missile for successfully guided flights requires the consideration of the following factors:

(a) Distribution of missile end course trajectories (distribution of miss-distance).

(b) Position of fuze triggering point along each possible missile trajectory.

(c) Fuze delay.

(d) Warhead burst pattern.

(e) Vulnerability of the target aircraft.

CARDE PROPOSES A PROGRAM OF FLIGHT TRIALS UNDER ECM CONDITIONS ("END RUN")

Factors which would contribute to an overall statistical study are the distribution of aspect and of missile heading error and range at launch, since this will affect the miss-distance distribution. The distribution of aspect at launch depends on the course difference of attack, so that if an assessment were to indicate a favourable launch aspect, this might be obtained by proper choice of course difference.

The distribution of end course trajectories for a radar-guided missile homing on a large multi-engined target has never been satisfactorily determined. On small targets, for rear attacks, Sparrow II has been found to have an approximately circular gaussian distribution of miss-distance. This, however, is a case where one reflection point (the engine tail pipe) predominates. For lethality studies conducted at CARDE, the distribution of miss-distance for a large target is assumed to be rectangular with gaussian tails. This reflects the wandering of effective radar target over the aircraft.

A microwave fuze may be postulated to trigger on the first normal surface, or the first reflecting corner, which the fuze beam meets. The burst position of the warhead is then delayed by amount computed in terms of closing speed - this is equivalent to a fixed distance delay. Optimum fuze delay varies with warhead type, the aspect of approach, and the miss-distance. In the determination of operational doctrine, some decision must be made as to the preferable approach aspect, so that a favourable fuze setting may be made.

In the CARDE assessment, the Sparrow II fragmenting and continuous rod warheads were compared in attacks on the Bear subsonic turboprop bomber. Since no complete vulnerability analysis of the target has been made, the results of this work must be considered approximate. For the fragmenting warhead, the vulnerable elements are the pressure cabin and crew, the control lines (a very small contribution), and the bombing/navigation system. For the continuous rod warhead these sources of kill remain, and are augmented by the possibility of primary structure kills of the fuselage. In both cases direct hits can be assumed to provide a significant contribution.

Table XII below, gives the results of the lethality assessment for the subsonic target. Although it must be stressed again that the results are only approximate, trends and order of magnitude are thought to be correct.

MORE COMPLETE LETHALITY ASSESSMENT IS REQUIRED.

TABLE XII

Aspect	Fragmentation		Continuous Rod	
0° Tail	P_K % =	21	P_K % =	39
30°		16		33
60°		16		36
90° Beam		22		42
120°		17		38
150°		12		30
180° Head-on		17		24

Table XII - Results of Lethality Assessment for Sparrow II Warheads against Bear target. (Fuze delay constant for all aspects, = 15 ft.)

Bearing in mind the approximate nature of such an analysis, these results show no favourable aspect of attack, and point out the probable superiority of the continuous rod warhead for the attack of large targets by a guided missile.

12.0 PLACEMENT WITH MB-1 LONG RANGE ROCKET

When considering the MB-1 rocket from a placement point of view, about the only difference between this weapon and a guided missile is the fact that allowable heading error is essentially 0°. However, placement probability does not vary too greatly with heading error so that placement results for the rocket are essentially the same as for Sparrow. For the subsonic case of Mach target .95, results in P_p are within 1%, of the missile case, both co-altitude and snap-up attacks. Only at very low AI ranges (less than .2S) are changes more noticeable. Then, for $\sigma = 1.5$ degradation is about 5%, for $\sigma = 3$ degradation is about 10%. Placement probabilities for Supersonic case are outlined in the following Tables. Except for AI ranges less than .6S, they are identical with the missile case.

CONTINUOUS ROD WARHEAD APPEARS TO BE TWICE AS EFFECTIVE AS FRAGMENTING TYPE.

TABLE XIII

$\Gamma = 135^{\circ} \quad \Delta h = 0$

AI Range / σ	.2S Missile	.2S MB-1	.4S Missile	.4S MB-1	.8S Missile	.8S MB-1	1.0 Missile	1.0 MB-1
1.5	95	90	100	100	100	100	100	100
3.0	70	65	98	98	100	100	100	100
4.75	45	40	90	91	99	100	100	100
6.75	35	30	76	79	95	96	97	98
9.0	25	20	65	66	90	90	93	95

TABLE XIV

$\Gamma = 110^{\circ} \quad \Delta h = 0$

AI Range / σ	.4S		.5S	
	Missile	MB-1	Missile	MB-1
1.5	91	83	96	96
3.0	64	51	89	72
4.75	55	34	61	49
6.75	34	25	45	46
9.0	25	18	35	28

TABLE XV

$\Gamma = 110^{\circ} \quad \Delta h = 20K$

AI Range / σ	.4S		.5S	
	Missile	MB-1	Missile	MB-1
1.5	95	85	98	95
3.0	75	55	84	84
4.75	56	35	70	65
6.75	41	25	68	49
9.0	34	20	48	38

TACTICAL USEFULNESS OF MB-1 IS DOUBTED.

Although MB-1 does not present a problem placementwise, if allowable heading errors are very small, then the stability of the fire control in maintaining this launching tolerance may be important. This aspect has not been studied at CARDE.

Also, it should be noted that methods of homing under ECM, as described in Section 10, require about 10° heading tolerance on the weapon and are therefore not applicable for the MB-1 weapon.

Conclusions

1. Under favourable conditions, placement probability for Arrow with MB-1 is as high as for Arrow with Sparrow.

2. Actual tactical usefulness of MB-1 is doubted.

13.0 IR MISSILES

Some work was done on the effects of using an IR missile. The best indications that could be obtained on launch zone was that this zone would be similar to the radar case, except that a 30° cone must be deleted from the nose portion of the zone. This 30° restriction is both horizontal and lateral. Placement results for this case indicated that for co-altitude attacks placement is very low, except for near beam attacks ($\Upsilon = 110^{\circ}$). Here, for $P_p = 95\%$, σ of 1.5 n.m. is required. Differential altitude for 10K ft. does not improve the situation for either snap-up or climb. However, for differential altitude equal to 20K ft. snap-up attacks gave results which were as good as for the radar missile. However, climbing attacks with 20K ft. altitude difference still gave poor placement probability.

Summary

1. Co-altitude - low probability.
2. h = 10K - no improvement.
3. h = 40K climbing - low probability.
4. h = 40K snap-up - high probability.

IF AN IR MISSILE IS USED, SNAP-UP FROM 20,000 FEET BELOW THE TARGET.

14.0 ASTRA IR SUBSYSTEM

A number of difficulties in the IR subsystem have been resolved with RCA. Two unresolved items include target radiation and the question of providing independent stabilization for the IR subsystem.

14.1 Targets

The expected target radiation from Bison, Badger, Bear and Blowlamp are fairly well established. This is such as to preclude a large forward detection range except in the case where Blowlamp might be using reheat. It has not been possible to resolve the characteristics of any target faster than Mach 1.2. One might extrapolate from the characteristics of contemporary U.S. Aircraft and in so doing would achieve detection ranges of 20 to 30 miles in the forward hemisphere. Such an extrapolation is dangerous because it implies the use of reheat when in practice sufficient performance might be obtained through the use of a convergent-divergent nozzle. With this configuration there is no indication of the probable thermal radiation. It appears that the judgment of target radiation in terms of contemporary Russian Aircraft is conservative.

14.2 Stabilization

The IR telescope is mounted in the tail fin. Provided that its physical separation from the radar system does not introduce large boresight errors, there may be no requirement for independent stabilization.

Introduction of independent stabilization would involve a substantial engineering change leading to undue delay in production of a system. However, study of possibility of introducing such a system at a later date would appear desirable if it is suspected that ECM conditions may completely degrade the fire-control system.

CARDE's attitude has been that the fire-control system is unlikely to be completely degraded. It is quite possible that the angle tracking errors may increase to five degrees and no range tracking information may be available until very late in the intercept. Accepting slight degradation of the radar, it would seem advisable to optimize for IR tracking rather than IR search. A narrow field of view is mandatory in providing this angular accuracy and giving sufficient discrimination to resolve targets in a formation.

PROCEED WITH DEVELOPMENT OF THE IR SUBSYSTEM.

14.3 System

CARDE endorses the changes suggested by RCA in their report MRO-7-599A-37 for these seem to lead to the possibility of producing an effective system in the shortest possible time. There may not be very much growth potential in the system since it is not independently stabilized and does not use a gimballed detector but with the present state of the art for the targets envisaged, such new design features can hardly be incorporated in reasonable time.

The basic change is to substitute a small detector for a large area detector. RCA have been making an extrapolation of the state of the art in their assumptions about the characteristics of large detectors. Such assumptions seem unwarranted. Small detectors are immediately available, and may even be available with immersed optics in the relatively near future.

14.4 Conclusion

It is advised that the stage one proposed changes should go ahead and that a review meeting should be held in six months time to discuss the state of the art and to indicate what growth potential should be introduced into any future system and whether a stage II IR system is necessary or desirable.

15.0 LIMITS ON INTERCEPTOR MANOEUVRE

Some study was done on the effects of the interceptor turning at less than the maximum available g's. The Arrow is assumed limited to 4 g's maximum load factor; however, turns at this rate cause considerable deceleration. In some cases limiting of interceptor g's to some lower value improves placement chance. Conclusions must be based on what information is available to the interceptor.

1. If course difference is known, then the pilot could use the rule

   $180^\circ - 135^\circ$ - Pull maximum g's.

   $110^\circ - 90^\circ$ - Pull less than g limit (about 2g)

2. If polarity of the steering signal is known, more improvement could be obtained by

   (a) If lead angle is too great, pull maximum g's

   (b) If lead angle is too small, pull less than maximum (about 2g).

INTELLIGENT LIMITING OF MANOEUVRE TO IMPROVE P_p REQUIRES ASPECT INFORMATION.

3. If information is not available for (1) or (2), it is better on the average to always pull full g.

If tactics (1) and (2) can be used at course differences equal to 90°, some hopeless cases of P_p equal to 70% can be brought up to 98%.

16.0 MISSILES

In placement studies the weapon is characterized by its launch zone. This is defined by maximum and minimum range and heading limits within which a missile is to be fired. Reasonable variations in the values of these limits do not affect placement results substantially. Generally it may be said that if the launch zone has (2 sec?) depth between maximum and minimum ranges at all aspects and a tolerance on allowable headings at launch of the order of 8° then missile characteristics will not limit the value of placement probabilities obtained. As long as a guided missile has all-around attack capabilities there is little to choose between different types of first generation missiles from a tactical point of view.

16.1 Discussion of Sparrow II

Performance

The launch zones used in this work were chosen to represent the Sparrow II missile performance. There may be some doubts about the launch zone at high altitude. If the missile is launched at high speed (Mach 1.5 or higher), so that its average flight speed is above Mach 2.0, it has about 4 g manoeuvre capability available at 60K ft. This would be sufficient to give some launch zone.

Suggested methods of improving the situation to provide missile performance capabilities at even higher altitudes have been:

(i) Installation of a tracking head, with appropriate navigation changes.

(ii) Aerodynamic changes, especially tail-clipping, to increase manoeuverability at high altitudes.

It should be pointed out that either of these changes would require an extensive development program. Studies have indicated that improved launch zones would be obtained at high altitudes, but in the computer studies of aerodynamic changes it was assumed that manoeuverability would be doubled; but there is no confirmed evidence that tail-clipping alone would provide this improvement.

VARIATION OF MISSILE LAUNCH ZONE HAS LITTLE EFFECT ON PLACEMENT PROBABILITY.

Effectiveness

It has not proved possible to determine miss-distances to be expected in practice for Sparrow II. In computer studies at Douglas with a simplified representation of Sparrow II, ten out of ten runs from a given launch point must miss by less than 15 feet for this launch to be assumed as part of the launch zone. This corresponds to a miss-distance distribution with a standard deviation, centre of gravity to centre of gravity, of about 5 feet.

The root mean square miss-distance obtained in 1242-B and 1242-C missile flight trials was about 15 feet centre of gravity to centre of gravity. These trials have been made against small targets (F6F's, 45 ft. wing span) at low altitudes and in general launch conditions favourable to the missile were chosen. On the basis of tests of the NIKE, Douglas states that miss-distance distributions will not change with altitude. However, it may be said that the true effect of the following are not known:

(i) target size

(ii) target speed

(iii) altitude

Douglas have made a study which indicates 85% hit probability for a continuous rod warhead with an effective radius of 27 feet, against a B47 type target if the RMS miss-distance is 15 feet. However, if RMS miss-distance is scaled with target size, hit probability against a bomber might possibly be as low as 25%.

The possibility of starting fuel fires at high altitudes is excluded, and with its effective radius of 10 feet or less, Douglas find that the fragmenting warhead for Sparrow II would be ineffective.

DISTRIBUTION OF MISS-DISTANCE ON LARGE TARGETS IS UNKNOWN.

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